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TECHNICAL MEMORANDUM

LACIE PHASE III LABELING ERROR CHARACTERIZATION: FINAL REPORT

By

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PREFACE

This work was directed by the Performance Analysis Group of the CAMS Operations in support of Accuracy Assessment (SF4) involving many CAMS analysts for the initial assessment of the Phase III blind site segment estimates. These assessments were then reviewed by Performance Analysis Group for consistency of the data. The following personnel participated in the study:

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- E. J. Cooper and E. R. Magness for their substantial help in developing the tabulation technique and providing consistency and help on the evaluations.

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1. INTRODUCTION

This report presents the analysis of labeling errors in the final Phase III estimate by Classification and Mensuration Subsystem (CAMS) Operations during the Large Area Crop Inventory Experiment (LACIE) from a subset of blind sites in five U.S. Great Plains (U.S.G.P.) states: North Dakota, Oklahoma, Montana, Colorado, and Minnesota.

1. OBJECTIVES

The objectives of the performance analysis using the blind site data were to

a. Identify the causes of labeling error and the factors involved in either overestimation or underestimation of the small-grain acreage and to provide data for a more detailed study.

b. Quantify the labeling error of the dots used for the final classification estimate by CAMS Operations.

c. Summarize and report the results of these evaluations.

d. Transmit to CAMS Operations recommended suggestions in labeling procedures.

1.2 SCOPE

Because of manpower and time limitations and some lack of adequate ground-truth data, not all the U.S.G.P. states were included in the study. Of those states used, only a portion of the total blind site segments were evaluated for the same reasons. The five states studied and the number of segments used are as follows.

State	No. of segments used	No. of usable blind sites in the state
North Dakota	18	21
Oklahoma	11	15
Montana	10	23
Minnesota	6	12
Colorado	6	11

The states and segments were selected by Accuracy Assessment (AA) personnel. The ground-truth data consisted of large-scale photographs and overlays with the crop type indicated by field personnel of U.S. Department of Agriculture and a digital computer printout, provided by AA personnel, of the ground-truth in a matrix format of 209 coded numbers identifying the crop for each field.

The blind site ground-truth data are collected late in the growing season, thus permitting only the final season estimate to be used. Therefore, the results of this study are relative only to the final estimate passed to the Crop Assessment Subsystem (CAS). No mid-season data were used unless it was the last classification estimate.

2. BACKGROUND

One of the major sources of underestimation in the LACIE proportion estimates has been found to be the misidentification of small grains' signatures. However, this statistical value alone provides no insight on how to reduce this error source. The first step to a solution is to identify and quantify the reason for the mislabeling.

During the latter part of the 1976-77 growing season (Phase III), CAMS Operations personnel used the Procedure 1 dot processing technique (ref. 1) for estimating the acreage of small grains. The accuracy of the proportion estimate of small to nonsmall grains is normally compared to the actual proportion of small to nonsmall grains derived from the ground truth.

The proportion estimate represented the gross effect of all errors from all sources. Analyst labeling could also be quantified, but it was not specific enough to identify the causes of the individual dot labeling errors. Thus, a supplemental method was used on the blind site segments that had been developed for the intensive test site (ITS) segments; namely, labeling error characterization. This technique attempts to separate factors used in individual dot interpretation/labeling and relates labeling errors and causes to each other.

The CAMS analyst estimated the wheat acreage of a segment by image interpretation of production film converter (PFC) products as described in reference 2 and guided by the techniques of Procedure 1. This method of wheat acreage estimation is basically that of interpreting and labeling the upper left dot of a subset of the 209 grid intersections on the PFC products and using the spectral values of the labeled dots to provide the basis of the LACIE computer program to estimate the proportion of wheat in the segment. The labeling of the dots and the cause of the mislabeling are vital to the proportion estimate.

Procedure 1 required each analyst to use the same decision logic or deductive reasoning to interpret the imagery. The method of interpretation is basically a comparison of the fields' colors (spectral signatures) to each other throughout the growing season as manifested in the PFC imagery, primarily Product 1. Products 2 and 3 were used basically as ancillary data for the decisionmaking process.

Analysts tended to be conservative when interpreting imagery. To label a small-grain field or dot, the analyst had to have spectral and spatial evidence of small grain. This not only involved the dot that was to be labeled but also other dots on the imagery that were both similar and dissimilar to it. It was important for the analyst to follow the progression of all the signatures of all types through time (multiple acquisitions) and compare the progression with the expected phenological development of the small grain. If evidence suggested that the signature was that of a small grain, the picture element (pixel) was labeled small grain; otherwise, it was labeled nonsmall grain. This conservative rationale for labeling was necessary because the analyst had to base his judgment on repeatable evidence of physical conditions that were manifested in the spectral and spatial aspects of the imagery. Otherwise, the labeling decision would have been inconsistent, illogical, arbitrary, and less likely to be correct.

For example, in an Oklahoma segment during a drought-affected season when most of the wheat had turned, a narrow band of wheat, one pixel wide, around a small lake or pond developed phenologically more slowly than the rest of the wheat in the same field because of the greater amount of moisture available. The band of wheat remained a bright red, consistent with the heading stage; whereas the remaining portion of the wheat field displayed a dark gray or brown color on the PFC imagery, consistent with the turning signature. Because weeds, grass, and trees frequently grow adjacent to standing water in wheat-growing areas of the U.S.G.P., the nonsmall-grain vegetation would be manifested on the imagery as bright red when wheat is turning. When faced with this decision, the analyst would label the bright red band as nonwheat because this is the most frequent occurrence under these

conditions. The analyst could not be expected to *guess* that under *this particular* circumstance the red band was truly wheat and not grass or weeds.

During the 1977 harvest season in Oklahoma, a segment had acquisitions representing only the planting-to-early-emergence stage, a dormant stage, and the last acquisition well into the turning/ripening stage. The imagery showed a poorly emerged small-grain signature in the first stage; the dormant stage was not helpful. The final stage of the small-grain signature was so like the nonsmall-grain signature that the analyst missed a significant amount of small grain in the segment. Since he had no signature evidence of small grain in most of the small-grain fields, the analyst had to turn in a low estimate even though he probably surmised this area to be a high small-grain production area. He could justify the low estimate on the basis that numerous reports of drought were received for this area and that the low estimate would be consistent with that episodic event.

The conservative approach does bias the labeling toward underestimation of small grain. Under the circumstances, the analysts must continue in this manner until some yet unknown reliable information can be made available for interpretation.

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3. APPROACH

In the search of a better definition for the reasons and/or causes of erroneously labeled training fields or dots for Phase III ITS evaluations, an attempt was made to separate each repeatable facet of the image interpretation thought process and growth stages of small grains and then to tabulate the results per segment consistently. An effort was made to identify the various causes by separating the errors into separate spatial conditions (ref. 3). This study was useful in determining the influence of boundary pixels on the interpretation. However, the physical and interpretative conditions under which the pixels were labeled were not part of the statistical analysis. Such conditions that were not considered were

- Enumeration of the growth stages represented by the acquisitions available.
- Comparison of the majority of the wheat signatures' development to the expected normal wheat signature of the adjusted crop calendar.
- Various interpretative confusions.

This report expands upon the original concept of the labeling error characterization and hopefully improves the identification of the error causes and their relationships to each other.

The rationale of the labeling error characterization is to identify and tabulate the following:

- Each normal physical condition of the growth stages that could be reflected or deduced from single or temporal image interpretation of the imagery.
- The "normal range" of the temporal spectral colors for each condition of the growth stages for comparison of the abnormal colors in the imagery.
- The manifestations of the PFC imagery's spectral response to episodic events.

- The spectral capabilities of the acquisitions available and missing acquisitions that have influenced the interpretation/labeling.
- The various types of causes of labeling errors and their relationship to each other.

With this comparison of the normal to the abnormal data to identify errors, each error can then be tabulated and easily related to other error factors both logically and systematically.

Statistical analysis can then be applied to the relationship of the rate of error between various combinations of factors. Synthesis of these results can provide data to enable project management to attack the larger sources of error first and direct remedial action toward reducing the labeling error in the most efficient use of manpower and financial resources.

4. DESCRIPTION OF THE LABELING ERROR CHARACTERIZATION FORMAT

The labeling error characterization format evolved after many modifications of the data recorded over several months. The format included the description of various categories, rearrangement of the tabulation format, and grouping of similar factors and splitting of dissimilar or important factors.

The correct base acquisition was determined by examining the analyst's dot labeling form. The base acquisition used was the PFC acquisition selected for labeling the dots and registering all acquisitions for this temporal classification. All the analyst's dot labels were carefully recorded separately for both Type 1 and 2 dots on the dot comparison form (fig. 1) in a matrix of boxes in the format of the 209 dot intersections on the PFC imagery.

4.1 DOT COMPARISON FORM

The ground-truth identity of each dot was carefully recorded in the lower half of the box using the digital ground-truth information supplied by AA personnel. The computer-generated ground-truth data formed the basis of the unbiased assessment of the dot labeling error. The number of each correctly and incorrectly labeled dot of the small and nonsmall grains is recorded to the right side, line by line. The number of true border/edge boundary pixels is recorded to the left side in the appropriate small-grain or nonsmall-grain category based on the ground-truth printout. The count of boundary pixels recorded is the total number of boundary pixels (border/edge), whether or not the pixels were properly labeled. These are totaled at the bottom left side.

The total number of strip/fallow fields indicated by the ground-truth printout is recorded at the bottom center of the dot comparison form. The total number of labeled strip/fallow fields that had an integrated spectral signature was also listed. An integrated signature was a combination of two different spectral signatures of small fields that were averaged spectrally by the Land Satellite (Landsat) sensor's resolution capability as being

Segment number:			Classification acquisitions: 8135, 8020, 7197																							
Reference acquisition: 7197			Code: 38																							
Border/edge (B)			Pixel columns																					GT labels		Errors	
NSG	SG	Pixel line	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	NSG	SG	NSG	SG
		10							SG				SG									0	1	1	0
									SG				NSG									1	1		
	2	20				NSG		SG	SG[I]			NSG		NSG			SG			NSG		3	3	0	1
						SG		SG	175			175		NSG			SG			NSG		3	4		
	1	30							NSG		NSG				SG	NSG[B]	SG		NSG		NSG	1	2	0	4
									SG		SG[I]				SG	SG	SG		SG		NSG	1	6		
	1	40					SG[I]		NSG	NSG[B]									NSG			1	1	0	2
							175		SG	SG									175[I]			1	3		
		50							SG		SG			SG			NSG	SG				1	3	1	0
									NSG		175			SG			175	SG				2	3		
		60					NSG	SG	SG	NSG												4	2	0	1
							NSG	SG	SG	NSG												4	3		
		70									NSG			SG		NSG	SG	SG				1	3	0	1
											SG			175		175	SG	SG				1	4		
	1	80				DO[I]				NSG				NSG	NSG		NSG[B]	NSG				4	0	0	2
						SG				NSG				NSG	NSG		SG	NSG				4	2		
		90		NSG											DO		NSG					3	0	0	0
				NSG											NSG		NSG					3	0		
		100																						0	0
																						0	0		
		110		NSG			NSG															2	0	0	0
				NSG			NSG															2	0		
0	5	Totals																						2	11
																						22	26		

Total number of pixels (174, 175, 176, 177, 179, 224, 225, 226, 227, 229) labeled on ground-truth tape 8
Total number of integrated (I) signatures of 174, 175, 176, 177, 179, 224, 225, 226, 227, 229 4
Total number of I signatures (174, 175, 176, 177, 179, 224, 225, 226, 227, 229) labeled other 2

Error DO (designated other) DO (double disagreement)

Figure 1.— Dot comparison form.

somewhere in between the two signatures. The number of integrated strip/fallow fields (dots) that were labeled as nonsmall grains is also recorded at the bottom. To determine whether field signatures may be integrated or not, the evaluator assessed whether the strip/fallow fields were large enough or too small to be manifested on the PFC imagery as individual fields. If the fields were large enough, the analyst was expected to be able to label them correctly; therefore, the labels might or might not be in error. If the fields were too small to be separated spectrally and spatially, they were counted as an integrated signature; and the analyst's label was considered correct regardless of the difference with the ground-truth printout.

After all errors, boundary pixels, and strip/fallow fields were totaled, all areas of designated other (DO) delineated by the analyst were checked for any inclusion of small-grain labels, which would be automatic errors of omission and were recorded as such. The remaining dot labels, which show an agreement between the analyst and the digital ground truth, were checked for accuracy against the ground-truth photograph and overlay by careful manual comparison. If any labels were found in error, they were indicated on the dot comparison form and recorded on the segment tabulation sheet as double disagreement (DD) (fig. 2). The totals at the bottom right of the dot comparison form are the results of the labeling errors according to the AA digital ground truth. The numbers were the sums of the total nonsmall- and small-grain pixels labeled, followed by the total number of errors of nonsmall and small grains of those labeled. Included in the small-grain error were the number of small-grain dots excluded from classification by the DO area. (DO areas exclude all small grains, by definition.) The double disagreement errors were added only on the segment tabulation sheet.

4.2 SEGMENT TABULATION SHEET

The errors were listed on the segment tabulation sheet by each dot's discrete number according to its location on the matrix of 209 dots (fig. 3). This matrix of Type 2 dots is registered to the dot comparison form for convenience of identifying the pixel number. Only the Type 2 dots are explained here. (The Type 1 dots were evaluated in the same manner).

Blind site no.:											Acquisition: 7197, 8020 (base), 8135		
Dot type	Dot no.	Condition	Acquisitions available								Confusion vegetation	Cause	Identify all crops of 2.0 and 2.2
			a	b	ê	g	x	x	x	x			
2	11	4			F	A					2.0	γ	Millet
2	23	1											
2	45	1											
2	47	1									3.0	ϕ	
2	52	1											
2	55	1											
2	64	1									3.0	λ_2	
2	65	1									3.2	π	
2	83	4		A	A						2.2	λ_2	Hay
2	101	1									3.2	π	
2	123	1	B	D	A	A					3.0	θ	
2	148	1									3.0	π	
Disagreement													
2	23	1										κ	Hay
2	45	1										κ	Natural vegetation
2	52	1										κ	Fallow
2	55	1										κ	Fallow
Double disagreement													
2	137	1									3.0	π	DO area; borders pasture
2	165	4	B	D	D	D					3.0	θ	

Figure 2.— Segment tabulation sheet.

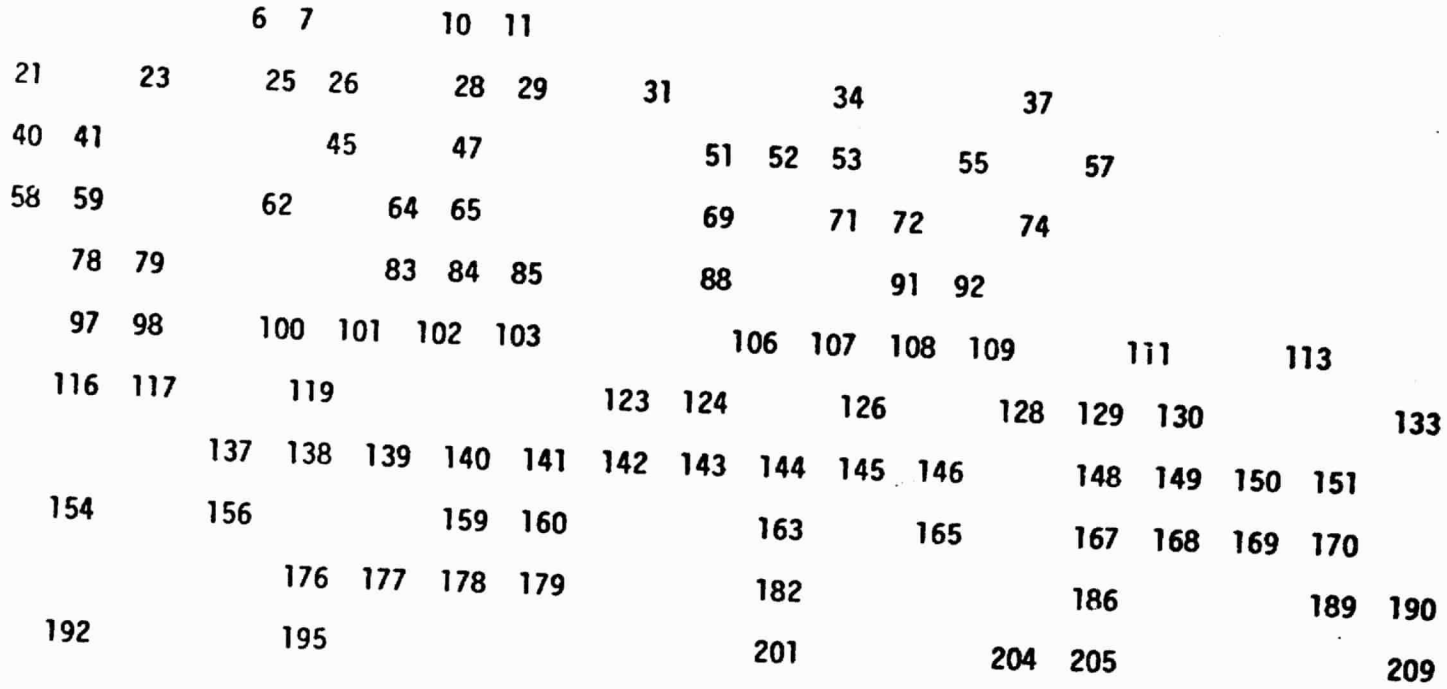

Figure 3.— Matrix of Type 2 dots.

On the segment tabulation sheet, the signature for each dot was evaluated individually for its representation of the growth stages in available acquisitions, confusion crops or conditions, and the apparent cause of the error. In addition, the labeling error evaluation provided a list, under the disagreement category, of those pixels that were not in error but would appear so because of registration constraints in the computer program and, under the double disagreement category, of those that were in error about which the analyst and the computer program were in agreement.

4.3 STATE TABULATION SHEET

The results of the tabulation of errors for each segment were recorded on the state tabulation sheet (fig. 4). The raw data of this study are presented on the state tabulation sheets for each state in the appendix.

The state tabulation sheet records the error causes by segment (vertically) and the causes by error group (horizontally) in part A. The total number of pixels per cause, separated into omission and commission, are recorded along the right-hand margin with the applicable percentages adjacent to them. The total number of pixels on each line represents the total error of their category of either omission or commission. The sums of the number of pixels labeled per category are recorded in part B of the form.

The numbers of the basic data group (part B) represent the total number of pixels labeled, separated into omission and commission and summed as total pixels labeled. The numbers in the digital matrix totals represent the omission and commission errors and represent the error tabulation of the digital ground truth determined from the comparison by the computer of its digital ground truth and the analyst's labels. The labeling error characterization evaluation totals express the error totals of omission and commission of the errors per segment recorded in each error type on the state tabulation sheet (part A). These totals reflect the adjustments for the errors of disagreement and double disagreement.

Symbol	Segment																		Total	Percentage
x																				
α																				
β																				
γ_1																				
γ_2																				
ε																				
λ_1																				
λ_2																				
μ																				
π																				

(a) Part A.

Figure 4.— State tabulation sheet.

Symbol	Segment																		Total	Percentage
φ																				
ω																				
θ																				
ν																				
δ																				
κ																				
σ																				
B																				
DD																				

(b) Part A — Concluded.

Figure 4.— Continued.

Error group	Segment																		Total	Percentage
Basic data totals																				
SG labels																				
Other labels																				
Total labels																				
Digital matrix totals																				
Omission errors																				
Commission errors																				
Total errors																				
Labeling error characterization evaluation totals																				
Omission errors																				
Commission errors																				
Total errors																				

(c) Part B.

Figure 4.– Concluded.

The category of disagreement is not an error in the labeling *per se*, but rather a record of the differences between the computer registration of the imagery to the ground-truth photograph and the comparison of the two by the labeling error evaluation. These differences result from misregistration or mislabeling. Most of the differences were caused by the computer's misregistration of a pixel category near a boundary with another field of a different category. The computer subdivides each pixel into six subpixels. Use of the "rule of majority" by the computer, of the spectral value of each subpixel, forces the computer to decide in favor of the majority. However, these dots clearly show, by comparison of the PFC image to the ground-truth large-scale aerial photograph and overlay, that the spatial and spectral properties belong to the other category. These disagreement pixels were assigned the kappa symbol (K) and recorded on the segment and state tabulation sheets.

The second cause of disagreement, personnel's mislabeling of the field on the overlay, seldom occurs. This error was detected through a careful comparison of the temporal signatures of the PFC imagery. This disagreement is recorded in the sigma category (σ) on the segment tabulation sheet.

The double disagreement values are the additional pixels about which analyst and the digital ground truth agree. However, during the labeling error evaluation, evidence showed that the pixel was of another category. Double disagreements (DD) were recorded at the bottom of the state tabulation sheet.

In all comparisons of the ground truth to the imagery, the ground truth was considered correct until proven differently. The disagreement values added to the labeling error evaluation totals match the ground-truth matrix totals.

The total number of border/edge pixels, regardless of error, is recorded on the designated line of the state tabulation sheet. The data provide the basis for the percentage of boundary pixel errors of the total pixels labeled that occurred for each segment and the average occurrence of border/edge pixel for each state.

5. CAUSE CATEGORIES AND THEIR USE

To evaluate the labeling accuracies correctly, the conditions under which the CAMS analyst worked should be recreated to the same degree as much as possible. This approach then requires consideration of the data available to the analyst and of the method of operation required by Procedure 1.

5.1 AVAILABLE ACQUISITIONS

All of the acquisitions that were available in the segment packet to the analyst at the time of the labeling for the classification estimate are to be considered, even those acquisitions that are not used for processing. Although some acquisitions are not used for the estimate, the spectral condition of these acquisitions still influences the labeling decision. Even those with clouds and some snow cover contributed value toward the interpretation and labeling. Those acquisitions that were placed in the segment packet after the analyst's estimate were not used for the labeling error characterization evaluation because they were not available to the analyst for the classification.

After determining the acquisitions available for the estimate from the segment packet data, the labeling error characterization evaluator placed the acquisitions on a light table and assigned a growth stage symbol to each acquisition, represented by a lowercase letter, as indicated below.

Symbol	Growth stage	Normal expected color
a	Planting through emergence	Gray, black, generally black
b	Postplanting, postemergence	Less dark, brighter soil type signature as it dries
c	Postemergence, jointing	Pinking up
d	Dormancy	Pink to dark gray or green
e	Jointing through heading	Pink to red
f	Turning, ripening	Mottled red, yellow, olive, and grayish green
g	Harvest	White, green
h	Postharvest	Pinking up, dark green-brown

The colors or shades were used as a guide or general description to convey the tone of the acquisition's colors and are by no means the complete list of shades and colors for each stage. The interpreter expects to see some variations of shade for the same crop, both of which are in the same growth stage.

The assignment of the growth stages to the acquisitions was determined by the small-grain signature of the majority of the small-grain fields to be of a certain growth stage. This assignment was made for each acquisition available. Each growth stage was recorded only once on the segment tabulation sheet even though there may have been more than one acquisition for a particular stage. Under multiple acquisition conditions for a growth stage, all the applicable acquisitions to a single growth stage were averaged by the evaluator.

5.2 ERROR ASSESSMENT OF INDIVIDUAL PIXELS

Each error pixel was listed on the segment tabulation sheet in numerical order from the dot comparison form along with its type (1 or 2). Each dot type was assessed separately by group. On figure 2, the Type 1 dots are not listed to avoid redundancy of explanation.

The latest acquisition available for classification was the sole acquisition upon which the judgment was made for the determination of the adjusted crop calendar (ACC). The majority of the signatures for small-grain fields of that last available acquisition determined the designation of the ACC. As indicated before, some small-grain field signatures may be either ahead or behind the ACC on the particular acquisition. A comparison was made between the numerical value of the ACC, as scribed on the PFC image by the analyst, to the spectral signature of the majority of the small-grain fields. The overall spectral signature was allowed a range of color that would be reasonable for the scribed ACC value. The latest acquisition's signature was then assessed to be either in agreement with, behind, or ahead of the ACC. This decision was then applied to all the error pixels in the manner described in the condition category on the segment tabulation sheet.

5.3 CATEGORIES OF ERROR CAUSES

5.3.1 CONDITION

If the error pixel was labeled small grain in the digital ground-truth printout, the condition is either

- 1 = in agreement with the ACC.
- 2 = behind the ACC.
- 3 = ahead of the ACC.

If the error pixel was labeled as nonsmall grain in the digital ground-truth printout, the condition is either

- 4 = in agreement with the ACC.
- 5 = behind the ACC.
- 6 = ahead of the ACC.

5.3.2 CONFUSION VEGETATION

This category indicates the crop or vegetation with which the pixel's (field) spectral signature was confused. The list below explains the meaning of the symbols. Those confusion crops of the "other" category were written on the right-hand side of the segment tabulation sheet.

1.0 Winter wheat labeled other: Confusion crop cannot be determined.
- 1.1 Winter wheat confused with spring grains
- 1.2 Confused with hay or alfalfa

2.0 Nonwheat labeled wheat: Confusion crop cannot be determined.
- 2.1 Confused with spring grains
- 2.2 Confused with other small grains
- 2.3 Confused with winter grains

3.0 Spring wheat labeled other: Confusion crop cannot be determined.
- 3.1 Spring wheat confused with winter grains
- 3.2 Confused with hay or alfalfa

5.3.3 ACQUISITIONS AVAILABLE

Lowercase letters were recorded at the top of the column labeled "acquisitions available" to indicate the growth stages represented by acquisitions. The letters correspond to the growth stages listed in section 5.1. The behind (<) or ahead (>) symbol over a letter indicates that the spectral response for that growth stage, manifested by the spectral response of the majority of the small-grain fields, was either behind or ahead of the ACC. If no symbol is written over the letter, the growth stage was in agreement with the ACC.

For expediency, only the abnormal colors of the error pixel were indicated under the corresponding growth stage by uppercase letters. The abnormal colors are listed in the table below. The blank areas for each pixel's growth stage indicate that the color for that particular growth stage was within the normal or expected range.

Code	Abnormal color
A	Pink, red
B	Dark gray to black
C	Purple, dark brown, dark gold, etc.
D	Yellow, gold, tan (lighter than C)
E	Whitish pink to gold to yellow
F	Green, blue

5.4 EXPLANATION OF THE ERROR CAUSES

The various causes of error are listed below with the corresponding explanation and symbol.

α = Insufficient acquisitions. A lack of informative acquisitions (those useful to the estimation) contributed to the cause of the labeling error. (Acquisitions that are hazy or cloudy, etc., or more than one acquisition in the same biostage may be only partially useful.)

β = Poor stand of small grain, usually caused by abnormal weather conditions or cropping practices. (Reserved for use with 18-day field observations for specific fields.)

γ = Abnormal development of small grain.

γ_1 = Behind ACC (late planting and development).

γ_2 = Ahead of ACC (early planting and development).

ϵ = Narrow strip fields. Single narrow fields — The field's signature may or may not be overridden by surrounding signatures.

λ = Clerical error.

λ_1 = Wrong acquisition used for labeling, which is the base acquisition. Analyst simply wrote the wrong acquisition number.

λ_2 = The error pixel which clearly followed a temporal sequence for its category. Since other pixels with the same temporal sequence were consistently identified correctly, then this error pixel was most likely misidentified.

μ = Double cropping practice of a second crop or weeds which have become the dominant signature and caused the increase in the infrared response after harvest.

π = Border/edge pixel, indicating spectral and spatial confusion between two or more fields of different types.

ϕ = Unknown cause. Error does not apply to any of the known causes.

χ = Weak small-grain signature. Temporal color sequence is followed, but colors are subdued.

ω = Field destroyed by grazing, plowing, disking, etc.

θ = Signature of a small grain that does not follow the expected temporal color sequence of small grain throughout the acquisitions.

ν = Signature of a nonsmall grain that does follow the expected temporal color sequence of small grain throughout the acquisitions.

τ = Volunteer wheat signature that does follow the temporal color sequence. Labeling from volunteer wheat was considered an error only after the availability of an acquisition in which a plowed-up signature occurred.

δ = Small-grain signature confused with nonsmall grain signature.

η = Nonsmall-grain signature confused with small-grain signature.

κ = Disagreement with AA digital ground truth.

σ = Disagreement with ground-truth map (field) label.

5.5 APPLICATION OF THE ERROR CAUSES

The determination of the error causes is somewhat subjective, since someone other than the analyst has ascertained the causes of the errors. Even though the analyst was consulted as to why the error was made, except errors with obvious reasons, it was difficult for the analyst to remember the reason for labeling the pixel as he did. To maintain as much objectivity and consistency as possible, a second person reviewed each error analysis. It is believed that the result of the error analysis is reasonable and quite accurate; the exact accuracy is not known.

A discussion of how each error cause was used follows.

- α — Insufficient acquisitions, which are usually caused by the clouds obscuring the scene at the time of overpass of Landsat. This physical constraint is an overriding factor in the evaluation of errors. For example, in Oklahoma, during Phase III, a particular area had a large amount of abandoned wheat. There were only two acquisitions — one during early emergence and the other in senescence, or after the small grain began to ripen (turning). For an analyst to determine that a field was abandoned, the wheat must be abandoned before senescence with sufficient time for the Landsat imagery to reflect the change. A reasonable amount of small-grain fields should be harvested so that a comparison can be made. Last, an acquisition must be obtained at this stage. For this Oklahoma segment, the analyst had confusion with the other harvested small-grain fields and no visible temporal evidence to

prove abandonment. The cause assessed to this type of error could have been that small grain did not follow the temporal color sequence of small grain (θ), that small-grain signature is confused with nonsmall-grain signature (δ), or that the field was destroyed by plowing, grazing, etc. (ω).

- β – Poor stand of small grain. This cause was determined during the labeling error evaluation, but re-evaluation suggests that "poor stand" should be reserved for evaluation in which the specific field of the error pixel has a record of the 18-day observations to support it. The β poor stand causes that have been verified (usually on ITS segments) showed the field to be retarded in growth or behind the ACC. Therefore, for this final synthesis of five USGP states, the errors counted in this category were included in the (γ_1) abnormal development of small grain.
- γ – Abnormal development of small grain (wheat). Both types of causes (γ_1 and γ_2, behind and ahead) are related to the growth stage of the specific field that the error pixel represents to the ACC value of the last acquisition. Regardless of the growth stage of *most* of the small-grain fields, this cause was assessed to a particular field. The evaluation of all data from the five states suggests that the λ_1, behind-the-ACC cause, should include the number of errors from β poor stand and χ small-grain signature as well.
- ε – Narrow strip fields. This cause is similar to the border/edge problem but is partly due to the scanner resolution's inability to differentiate the small size field, which is an isolated field.
- λ – Clerical errors. Clerical errors are of two types:
  - λ_1 – Wrong acquisition used for labeling. This cause stems from the analyst's use of a different acquisition for labeling the pixels than that indicated on the CAMS evaluation form as the base acquisition. The acquisition indicated was misregistered from the one used for labeling.
  - λ_2 – Inadvertent error. This is used only when a signature has been correctly labeled several to many times and then mislabeled once or twice all on one acquisition.

- μ – Double cropping practice. There is little difficulty in understanding this cause or its use.
- π – Border and edge pixels. Border pixel is the result of confusing identification between two different field types. The spectral signature is similar to both types by integration of the spectral reflectance, and the location of the pixel is on the border of both fields. An edge pixel error should not occur for Type 1 dots because of the requirements of Procedure 1, but it does sometimes. The edge pixel is clearly in one field or another in several acquisitions. The analyst did not recognize that the pixel changed location to a different field and thought it was a pure pixel, when in fact, due to a one-pixel shift in registration between two acquisitions, the error pixel changed crop type.
- ϕ – Unknown cause. Sometimes the evaluator cannot determine reasonable evidence for the error.
- χ – Weak small-grain signature. This reason for labeling error was used for the evaluation, but only a few pixels were assigned to it. Review of the five-state data would suggest that this reason should be grouped together with the γ_1 of abnormal small-grain signature since it is almost the same condition (behind).
- ω – Destruction by plowing, grazing, etc. This cause requires the use of specific field data. It is not often that a specific field is observed closely enough that the analyst can be sure this type of event occurred.
- θ – Small-grain signature that does not follow the temporal color sequence.
- υ – Nonsmall-grain signature that does follow the temporal color sequence. Both θ and ω may override the importance of other causes that may also be true, much like the α causes do, and generally for the same kind of reason. For instance, an error may be also caused by the fact that it is a poor stand (β); but if the signature does not follow the expected temporal color sequence which is the basis of the image interpretation for small-grain classification, then the analyst cannot correctly label the pixel.

- τ — Volunteer wheat error that can be used only when ground-truth data for a specific field are available to the evaluator.
- δ — Small-grain and η nonsmall confusion errors that were used relatively little. They were used when the confusion occurred, and no other evidence was observed to support a different reason for the mislabeling. Re-evaluation of these causes suggests that they are too vague and that their use should be discontinued.

Disagreement factors were not causes of analyst labeling error but reasons for the labeling error characterization evaluator to disagree with the digital ground truth. These pixels were used to increase the labeling accuracy above the error rate determined by the digital ground truth.

6. RESULTS

The subset of the segments in Oklahoma and Colorado do not appear to be as representative of their states as they should. The results obtained from the LACIE proportions are somewhat different from those of this labeling study for Minnesota and Colorado. However, the data set was included in the study because it was all that was available. The number of segments used in the study and the number of segments available by state are as follows.

State	No. of segments available	No. of segments used in study
North Dakota	21	18
Oklahoma	15	11
Montana	23	10
Minnesota	12	6
Colorado	11	6

6.1 STRIP/FALLOW FIELDS

The area extensively covered by strip/fallow fields is usually in the northern tier of the states. It was believed, prior to the labeling error characterization, that analysts would tend to label the strip/fallow areas as "other" crops rather than as small grains. If this were true, it would contribute to the underestimation of the LACIE proportion estimates.

The labeling error characterization evaluators made a special tabulation to establish the facts. The labeling errors for strip/fallow were separated into two groups. The first group consisted of pixels that were identifiable; the second, of pixels that had an integrated signature in which the separation of the strip fields could not be distinguished on the PFC imagery. Because half of the integrated signature strip fields were labeled "other," strip/fallow fields did not contribute to the underestimation of the LACIE proportion estimates.

State	Total strip/fallow dots labeled, %	Total strip/fallow with integrated signature, %	Total integrated signature dots labeled other, %
North Dakota	4.2	1.5	0.8
Oklahoma	–	–	–
Montana	22.4	10.3	5.7
Minnesota	1.1	1.1	1.1
Colorado	6.8	6.8	3.3

6.2 INSUFFICIENT ACQUISITIONS

The labeling error characterization evaluation showed that the error rate of a segment was very high for those CAMS classification estimates for which insufficient acquisitions for two important growth stages were not available for an estimate. If these particular segments were used for the aggregation, then the LACIE proportion estimates would not be representative of the CAMS estimates. Therefore, better aggregation results could be obtained if "short-changed" segments were precluded by CAMS from the aggregation.

Table 1, Comparison of Growth Stage Availability to Labeling Error, shows that three growth stages are required for the best, consistent labeling: post-emergence (b), jointing through heading (e), and either turning (f) or harvest (g). It was not possible for this analysis to separate the value of stage (e) from that of (f) because the analyst interprets by comparing the more vigorous plant stage of (e) to the less vigorous plant stages of (f) and (g). The postemergence stage (b) is needed to separate and fix the beginning of the growth cycle. One might also conclude that stage (a), planting through emergence, was not important. However, when mixed segments are involved, the planting date becomes important to separate the spring from the winter grains. If the available acquisitions had only an (a) stage and an (f) stage, the analyst would find it difficult to determine the senescence because he would not be able to compare the vitality of the (f) stage signature to a vigorous signature. Therefore, an analyst's confusion between natural vegetation and other crops would very likely occur.

TABLE 1.— COMPARISON OF GROWTH STAGE AVAILABILITY TO LABELING ERROR

Segment no.	State	Total no. of a pixels (a)	Total error, % (b)	Growth stages not represented (c)	Available growth stage represented (d)
1366	Okla.	37	39.8	b, c, e, g	a, d, f
1635	N. Dak.	5	36.2	b, c, f, g	a, e
1604	N. Dak.	29	31.0	b, e, f, g	a, c
1613	Minn.	–	26.0	a, f, g	b, c, e
1606	N. Dak.	–	23.2	c, f	a, b, e, g
1652	N. Dak.	–	22.5	c, g	a, b, e, f
1356	Okla.	–	21.3	b, c, g	a, d, e, f
1616	N. Dak.	–	19.6	b, f	a, c, e, g
1648	N. Dak.	11	18.6	a, b, f, g	c, e
1233	Okla.	–	17.6	d, e, g	a, b, c, f
1948	Mont.	–	16.2	d, e, g	a, b, c, f
1236	Okla.	–	14.0	b, d, f, g	a, c, e
1913	N. Dak.	–	13.8	a, g	b, c, e, f
1223	Okla.	–	13.0	b, e, f, g	a, c, d
1734	Mont.	–	12.8	c, e, g	a, b, d, f
1005	Colo.	–	12.5	a, b, d, g	c, e, f
1625	N. Dak.	–	12.3	e, f	a, b, c, g
1619	N. Dak.	–	11.0	f, g	a, b, c, e
1048	Okla.	–	10.6	d, e, g	a, b, c, f
1661	N. Dak.	5	10.3	b, c, g	a, e, f
1220	Okla.	–	10.2	b, e, g	a, c, d, f
1521	Minn.	–	10.2	b, g	a, c, e, f
1637	N. Dak.	–	9.6	c, f, g	a, b, e
1537	Mont.	4	9.5	b, d, e, f, g	a, c
1512	Minn.	–	8.7	b, c, g	a, e, f
1899	N. Dak.	–	8.3	g	a, b, c, e, f
1231	Okla.	–	8.2	b, c, e, g	a, d, f
1529	Mont.	–	8.1	a	b, c, d, e, f, g
1523	Minn.	–	7.0	c, g	a, b, e, f
1008	Colo.	–	6.9	b, d, e	a, c, f, g
1544	Mont.	–	6.7	c, e, g	a, b, d, f
1520	Minn.	–	6.6	b, c, f, g	a, e
1622	N. Dak.	–	6.5	c, g	a, b, e, f
1730	Mont.	–	5.9	c, g	a, b, d, e, f
1522	Minn.	1	5.6	a, c, f	b, e, g
1532	Mont.	–	5.4	b	a, c, d, e, f, g
1663	N. Dak.	–	5.3	c	a, b, e, f, g
1099	Colo.	–	5.3		a, b, c, d, e, f, g
1242	Okla.	–	4.4	b, c, g	a, d, e, f
1640	N. Dak.	–	4.3	b	a, c, e, f, g
1531	Mont.	–	4.2	d, g	a, b, c, e, f
1927	N. Dak.	–	4.0	a	b, c, e, f, g
1011	Colo.	–	4.0	f, g	a, b, c, d, e
1081	Colo.	–	3.9	f	a, b, c, d, e, g
1507	Colo.	–	3.8		a, b, c, d, e, f, g
1228	Okla.	–	3.5	c, g	a, b, d, e, f
1104	Mont.	–	2.9	c	a, b, d, e, f, g
1219	Okla.	–	2.4	g	a, b, c, d, e, f
1929	Mont.	–	2.2	f, g	a, b, c, d, e
1903	N. Dak.	–	0	a, c	b, e, f, g

[a]Total number of pixels = total number of inadequate acquisition error pixels including Type 1 and 2 dots, omission and commission.

[b]Total percentage of error = total number of all error pixels, Type 1 and 2, omission and commission, divided by the total number of all pixels labeled Type 1 and 2, omission and commission, per segment.

[c]Growth stages not represented = no acquisition available for the labeling decision for the corresponding symbol.

[d]Growth stages represented = acquisitions available for the labeling decision for the corresponding symbol.

An overall view of table 1 clearly demonstrates that the labeling error rate is reduced as the available growth stages increase. The bottom of the list where the least percentage of labeling error occurs has most of the "available growth stage represented" column filled, in constrast to the higher error segments where the "growth stages not represented" column is filled more.

Two segments had most of their labeling error caused by the α, insufficient acquisition, error. A very high error rate is evident when this condition occurs. Both segments 1365 and 1604 are at the top of the list on table 1.

It would be reasonable to conclude from the results of table 1 that the availability of turning to harvest growth stages for labeling contributes to lower labeling error. The higher error rate is associated with the unavailability of turning to harvest growth stages. The following table shows the omission labeling error rate (Type 2 dots only) between the segments with and without postheading acquisitions.

With postheading acquisitions		Without postheading acquisitions	
With acquisitions	Without acquisitions	With acquisitions	Without acqusitions
b, e	b, e	b, e	b, e
16.6%	23.8%	27.6%	27.5%
	Number of segments per category		
30	7	10	3

The least type of growth stages that should be available for the optimum collection of acquisitions are early emergence (b), jointing to heading (e), and turning (f).

6.3 ADDITIONAL SIGNIFICANT CAUSES

6.3.1 BORDER/EDGE

One should not judge the results of table 1 as being totally caused by missing acquisitions (growth stages) because other causes also influence the results, such as border/edge (π) and small grains that do not follow the temporal color sequence (θ).

6.3.2 UNDERESTIMATION

Misidentification of small-grain signatures, which are omission errors, was one of the major sources of underestimation of the classification estimates during Phase III. The misidentification of nonsmall-grain signatures, which are commission errors, causes overestimation and comprises a relatively small percentage of the labeling error. The following table shows the omission and commission errors for all the Type 2 dots in the five states.

State	Omission		Commission	
	No. error pixels	No. pixels labeled	No. error pixels	No. pixels labeled
North Dakota	114	455	30	563
Oklahoma	77	318	43	440
Montana	38	297	17	498
Minnesota	32	145	9	206
Colorado	24	114	3	286
Total	285	1329	102	1993

$\frac{285}{1329}$ = 21.4% Omission Error $\frac{102}{1993}$ = 5.1% Commission Error

In the five states investigated, the omission error was 21.4 percent (1329 ÷ 285) and the commission error was 5.1 (1993 ÷ 102). The data showed that the interpretation tended to be conservative. The commission error was low throughout the LACIE program -- approximately 2 to 5 percent.

6.4 LARGEST ERROR CAUSES

A tabulation of the labeling accuracies and error causes for the Type 2 dots is presented in table 2. The labeling accuracies are given for both omission and commission errors in each state. The single segments from North Dakota and Oklahoma with high error due to insufficient acquisitions were excluded. Segments with high error due to strip/fallow fields from Montana were also excluded.

6.4.1 OMISSION ERRORS

The omission accuracies (OA) were calculated by:

$$OA = \frac{\text{Total number of correctly labeled small grain dots}}{\text{Total number of labeled ground-truth small-grain dots}} \times 100$$

The commission accuracies (CA) were calculated by:

$$CA = \frac{\text{Total number of correctly labeled nonsmall grain dots}}{\text{Total number of labeled ground-truth nonsmall grain dots}} \times 100$$

The causes of the labeling error are given for both the omission and commission separated in the table. To make the omission and commission error rates comparable between each state, the errors have been averaged by dividing by the number of error pixels per cause by the total number of labeled pixels at the state level.

The results of the causes of labeling error on table 2 show that 85 percent of the error causes was due to the following reasons (in descending order of the amount of error):

- Border/edge pixels.
- Small-grain signature that is significantly behind the temporal color sequence of the majority of the small-grain signatures.
- The acquisitions available which provided an insufficient representation of the crop growth stages needed for discrimination of the signatures.
- A small-grain signature that did not follow the temporal sequence of the small grain

TABLE 2.– EVALUATION OF LABELING ACCURACIES OF TYPE 2 DOTS OF PHASE III BLIND SITES IN FIVE U.S.G.P. STATES

Parameter	N. Dak.	Okla.	Mont.	Minn.	Colo.
Small-grain accuracy (omission), %	76.1	82.0	85.3	77.9	79.0
Nonsmall grain accuracy (commission), %.	95.3	90.2	96.2	95.6	99.0
Causes of error per total pixels labeled:					
Omission, %:					
Lack of acquisitions	1.5	3.0	0.5	–	–
Behind ACC	1.2	1.5	0.8	1.3	3.0
Ahead of ACC	0.8	0.6	–	0.8	–
Abnormal W signature	2.4	1.3	1.1	–	–
Abnormal N signature	–	–	–	–	–
Total border/edge pixels labeled	6.9	4.9	3.9	8.3	3.5
Border/edge pixel errors	3.2	2.2	1.0	3.7	1.5
Narrow fields	1.3	–	0.9	0.3	0.8
Clerical errors:					
Wrong acquisition used for base	–	–	–	–	0.3
Inconsistency	0.6	1.3	0.5	2.6	0.5
Unlike other causes	0.2	–	–	–	–
Double or second crop	–	–	–	–	–
Commission, %:					
Lack of acquisitions	1.0	–	–	–	–
Behind ACC	–	0.1	–	0.6	–
Ahead of ACC	–	–	–	–	–
Abnormal W signature	–	–	–	–	–
Abnormal N signature	0.5	1.3	0.9	6.3	–
Total border/edge pixels labeled	0.5	5.4	3.0	8.0	3.8
Border/edge pixel errors	0.7	0.8	0.6	1.1	0.8
Narrow fields.	0.1	0.1	0.1	–	–

TABLE 2.— Concluded.

Parameter	N. Dak.	Okla.	Mont.	Minn.	Colo.
Clerical errors:					
Wrong acquisition used for base.	—	—	—	—	—
Inconsistency.	0.5	0.6	0.5	0.6	—
Unlike other causes.	0.2	—	—	—	—
Double or second crop.	—	1.4	—	—	—
Breakout of commission error crops, %:					
Sorghum.	—	0.3	—	—	—
Alfalfa.	0.1	—	—	0.3	—
Grass.	0.1	0.6	0.3	1.1	—
Pasture.	0.1	0.9	0.8	—	—
Hay.	0.1	—	0.4	0.3	—
Spring small grains.	—	—	0.3	—	—
Trees.	0.1	0.1	0.1	—	—
Idle fallow.	1.0	0.8	0.4	—	0.8
Homestead.	0.1	—	—	0.3	—
Flax	0.2	—	—	—	—
Millet	0.1	—	—	—	—
Sunflower.	—	—	—	0.6	—
Sugar beets.	0.1	—	—	—	—
Abandoned wheat.	—	2.4	—	—	—
Corn	—	0.1	—	—	—
Cotton	—	0.1	—	—	—
Winter small grains.	0.4	—	—	—	—

6.4.2 COMMISSION ERRORS

Two types of crops were more repeatedly labeled small grain as confusion crops: grass and idle fallow. Both of these crop or land-use types occurred more frequently than the others in all five states.

In Oklahoma, the abandoned wheat cause was high, mainly due to the lack of acquisitions in the jointing-to-heading stage, which precluded the analyst from determining the difference between the fields that were abandoned and those that were in the turning stage.

6.4.3 GROUND-TRUTH ACCURACY

The discrepancy in the error rates between the digital ground truth and the labeling error characterization was measurable. The differences are caused, primarily, by the local misregistration of pixels, as described in section 4.3. The use of the digital ground truth for determining the accuracy of classification estimates should be used with caution. The difference between the two are shown below.

Ground-truth type	Error rate for all segments, %	
	Omission	Commission
Digital ground truth	28.4	8.9
Labeling error characterization	21.4	5.1
Difference	7.0	3.8

These differences represent a 33-percent increase of the omission error and a 42.7-percent increase in the commission rate.

It should be clearly understood that the labeling error characterization only evaluated those pixels of the 209-dot matrix that were labeled by the analyst. Although the remainder of the 209 dots were not evaluated, it would seem likely the discrepancy would apply to these others also.

7. CONCLUSIONS AND RECOMMENDATIONS

The Phase III labeling error characterization study shows that —

- The results of this evaluation for the states of Minnesota and Colorado are probably too meager to be conclusive. The addition of segments to the evaluation for these states would make the results more meaningful.
- Segments without one of the acquisitions representing early emergence, jointing to heading, and either turning or harvest had higher omission error rates. These segments with this condition should be excluded from the final classification estimate submitted for aggregation.
- Mislabeling of the strip/fallow field areas produced an equal amount of small grain and nonsmall grain. In areas of strip/follow, the labeling did not contribute to the underestimation problem because of mislabeling.
- Border/edge pixels caused the greatest amount of omission errors. If these pixels could be labeled by some method other than by analyst interpretation, the underestimation caused by the border/edge error might be reduced. Perhaps the analyst would only identify the pixel as border/edge; then some simple procedure or a statistical manipulation by the computer would be useful.
- The analysts basically did a fine job of labeling in Phase III. The omission error rate was 21.4 percent, and the commission rate was 5.1 percent. The major portion of the underestimation (omission error) was caused by factors beyond the control of the analyst following the interpretation procedures as shown below.
- 85 percent of the total omission error for the five states in descending order was due to border/edge pixels (π), to small-grain signatures that were significantly behind the temporal color sequence of the majority of the small-grain signatures (γ_1), the acquisitions available that provided an insufficient representation of the crop growth stages needed for discrimination of the signatures, and small-grain signatures that did not follow the temporal color sequence of the small grain.

- The analyst will probably always have a conservative bias toward any target crop because he must have consistent evidence to support the existence of
- the target crop. Otherwise, vague suppositions and guesses between two choices will be underestimated.

8. REFERENCES

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APPENDIX

TABULATION SHEETS ON NORTH DAKOTA, OKLAHOMA, MONTANA, MINNESOTA, AND COLORADO

APPENDIX

TABULATION SHEETS ON NORTH DAKOTA, OKLAHOMA, MONTANA, MINNESOTA, AND COLORADO

The raw data used for tabulating labeling errors of type 1 and 2 dots for selected segments in North Dakota (18), Oklahoma (11), Montana (10), Minnesota (6), and Colorado (6) are presented in tables A-1 to A-10.

TABLE A-1.— NORTH DAKOTA PHASE III BLIND SITE DATA — TYPE 2 DOTS

Symbol	Segment																		Total	Percentage
	1602	1604	1606	1616	1619	1622	1625	1635	1637	1640	1648	1652	1661	1663	1899	1903	1913	1927		
X																				
α		12						3											15	13.2
		4						1			4		1						10	33.3
β																			0	
γ_1	5			1	1				1			1					3		12	10.5
γ_2								5				1		2			1		9	7.9
ε							2				3	2					6		13	11.4
							1												1	3.3
λ_1																			0	
λ_2	1		2		2			1											6	5.3
		1	1			1	1		1										5	16.7
μ																			0	
π	5		4	4		2	1	3	1	2		4		1	5			1	33	28.9
	1							1		1	1				3				7	23.3

TABLE A-1.— Continued.

Symbol	Segment																		Total	Percentage
	1602	1604	1606	1616	1619	1622	1625	1635	1637	1640	1648	1652	1661	1663	1899	1903	1913	1927		
ϕ	1																		1	1.8
	1					1								1	5			1	2	
ε															3				2	6.7
																			0	
θ	1		2	6	2		2		2	1		4	3				1		24	21.1
ν																				
	1		1			1					1	1							5	16.7
δ																			0	
κ	5	1	5	1	4	2	4	5		3	1	3	2	4	2	5	4	1	52	11.4
	7			3	3	1	1	1		3	1		4		3	1	2	3	33	5.9
σ								1		2	1			1	1		2		8	1.4
						1											1		2	0.4
8	8	5	3	10	3	2	2	1	3	1	0	6	4	5	4	3	6	3	69	15.0
	3	2	2	0	3	2	1	7	1	6	5	4	1	4	3	4	0	3	51	9.4
DD	0	1		0		1	1	7	0	2	1	8		1	1	0	0	0	23	
		1	2		2	1	2			1	1		1						11	

TABLE A-1.– Concluded.

Error group	Segment																		Total	Percentage
	1602	1604	1606	1616	1619	1622	1625	1635	1637	1640	1648	1652	1661	1663	1899	1903	1913	1927		
Basic data totals																				
SG labels	38	29	26	41	32	32	17	16	19	25	19	19	19	30	37	11	27	18	455	
Other labels	26	31	22	19	28	28	37	21	33	35	38	32	36	30	23	49	33	42	563	
Total labels	58	60	47	60	60	60	54	35	52	60	57	51	55	60	60	60	60	60	1018	
Digital matrix totals																				
Omission errors	18	12	11	12	7	3	8	11	4	6	4	7	5	8	7	5	17	2	147	32.3
Commission errors	10	5	2	3	3	4	1	3	1	3	6	1	4	0	6	1	3	3	59	10.5
Total errors	28	17	12	15	10	7	9	14	5	9	10	8	9	8	13	6	20	5	206	20.2
Labeling error characterization evaluation totals																				
Omission errors	13	12	8	11	5	2	5	12	4	3	3	12	3	4	5	0	11	1	114	25.1
Commission errors	3	5	2	0	0	3	2	2	1	1	6	1	1	0	3	0	0	0	30	5.3
Total errors	16	17	10	11	5	5	7	14	5	4	9	13	4	4	8	0	11	1	144	14.1

TABLE A-2.— NORTH DAKOTA PHASE III BLIND SITE DATA — TYPE 1 DOTS

Symbol	Segment																		Total	Percentage
	1602	1604	1606	1616	1619	1622	1625	1635	1637	1640	1648	1652	1661	1663	1899	1903	1913	1927		
X																				
		12						1					3						16	20.3
		1									7		1						9	40.9
	1		2																3	3.8
Y_1	5		3	1	1			1				3							15	18.9
	1																			
Y_2	1							2						1					4	5.1
ϵ							2	1				2					1		6	7.6
λ_1			1																1	1.3
λ_2			4		1		1	1	2										9	11.4
		1	1		1							1							4	18.2
μ																			0	
π	1					1	1	1				1						2	6	7.6
	1				1			1				1							4	18.2

TABLE A-2.— Continued.

Symbol	Segment																		Total	Percentage
	1602	1604	1606	1616	1619	1622	1625	1635	1637	1640	1648	1652	1661	1663	1899	1903	1913	1927		
♦	4							1				1							6	7.6
								1										1	2	9.1
♣																			0	
♦			1	7	1		1	1									1		12	15.2
♥																				
											2		1						3	13.6
♠									1										1	1.3
♥	3		5		1	1	4	5	1	2		6			1		1		30	9.7
	1					2		4		2			2		2	1			13	4.4
♣				1		1								1				1	4	1.3
																1			1	0.3
B	1	1	2	0	0	0	2	2		2	1	3	0	0	1		1	0	15	2.8
	3	0	1				1	1	1	4	4	3				1	1		21	2.6
00	0		3	1	2	1	1	4	0		1	2		0	0	0	0	1	16	
		1										1	1						3	

TABLE A-2.– Concluded.

Error group	Segment																		Total	Percentage
	1602	1604	1606	1616	1619	1622	1625	1635	1637	1640	1648	1652	1661	1663	1899	1903	1913	1927		
Basic data totals																				
SG labels	47	20	26	22	21	13	13	12	12	22	9	20	11	12	23	3	13	11	310	
Other labels	12	21	22	14	10	19	31	22	19	12	31	27	21	22	13	30	21	28	375	
Total labels	59	41	48	36	31	32	44	34	31	34	40	47	32	34	36	33	34	39	685	
Digital matrix totals																				
Omission errors	26	12	14	8	2	2	8	10	4	2	0	11	3	2	1	0	3	2	110	35.5
Commission errors	2	1	1	0	2	2	0	6	0	2	8	1	3	0	2	2	0	1	33	8.8
Total errors	28	13	15	8	4	4	8	16	4	4	8	12	6	2	3	2	3	3	143	20.9
Labeling error characterization evaluation totals																				
Omission errors	12	12	11	8	3	1	5	9	3	0	0	7	3	1	0	0	2	2	79	25.5
Commission errors	1	2	1	0	2	0	0	2	0	0	9	2	2	0	0	0	0	1	22	5.9
Total errors	13	14	12	8	5	1	5	11	3	0	9	9	5	1	0	0	2	3	101	14.7

TABLE A-3.– OKLAHOMA PHASE III BLIND SITE DATA – TYPE 2 DOTS

Symbol	Segment																		Total	Percentage
	1048	1219	1220	1223	1228	1231	1233	1236	1242	1355	1365	1367								
κ				(a)				(a)												
π				(a)				(a)			23								23	29.9
∴				(a)				4											4	5.2
								1											1	2.3
γ_1	3		1	(a)		1		1		1									7	9.1
γ_2			1	(a)			4	(a)											5	6.5
ε				(a)				(a)												
										1									1	2.3
λ_1				(a)				(a)												
λ_2			2	2	2	1		2	1										10	13
				2		2		1											5	11.6
μ				(a)				(a)												
ν				3		4	2	4	1		3								17	22.1
			1				1		1	3									6	14.3

[a]Small fields procedure; no data.

TABLE A-3.– Continued.

Symbol	Segment																		Total	Percentage
	1048	1219	1220	1223	1228	1231	1233	1236	1242	1355	1365	1367								
ϕ																				
	1		2				1			5									9	20.9
ϕ																				
	1				1			1	1	7									11	25.5
θ	1			6			2			1									10	13
ν																				
	2						1			7									10	23.3
δ										1									1	1.3
κ	3		1	2	3	2	1	2	1		2								17	5.4
	7			1	1		1	1	2										13	2.8
ɔ																				
B	0	0	2	6	1	2	11	6	2	2	6								38	12.0
			2	4	3	4	2	7	3	15	2								42	9.1
DD	0	0	0	0	0	3		1	0	0	0								4	
							1	1											2	

TABLE A-3.– Concluded.

Error group	Segment																		Total	Percentage
	1048	1219	1220	1223	1228	1231	1233	1236	1242	[illegible]	1365	1367								
Basic data totals																				
SG labels	28	1	13	59	7	52	23	61	32	7	35								318	
Other labels	28	77	45	41	47	11	35	39	26	91	22								462	
Total labels	56	78	58	100	54	63	58	100	58	98	57								780	
Digital matrix totals																				
Omission errors	7	0	5	13	5	5	9	12	3	3	28								90	28.3
Commission errors	11	0	3	3	2	1	3	3	4	23	0								53	11.5
Total errors	18	0	8	16	7	6	12	15	7	26	28								143	18.3
Labeling error characterization evaluation totals																				
Omission errors	4	0	4	11	2	6	8	11	2	3	26								77	24.2
Commission errors	4	0	3	2	1	2	3	3	2	23	0								43	9.3
Total errors	8	0	7	13	3	8	11	14	4	26	26								120	15.4

TABLE A-4.— OKLAHOMA PHASE III BLIND SITE DATA — TYPE 1 DOTS

Symbol	Segment																		Total	Percentage
	1048	1219	1220	1223	1228	1231	1233	1236	1242	1355	1365	1367								
X																				
α											14								14	53.9
β																				
γ_1							1			1									2	7.7
γ_2							4												4	15.4
ε																				
λ_1																				
λ_2		1																	1	3.8
			2							1									3	30.0
μ																				
π											1								1	3.9
							1												1	10.0

TABLE A-4.— Continued.

Symbol	Segment																		Total	Percentage
	1048	1219	1220	1223	1228	1231	1233	1236	1242	1355	1365	1367								
ϕ										2									2	20.0
ω		1								2									1	3.9
																			2	20.0
θ		1	1				1												3	11.5
ν	1		1																2	20.0
δ																				
κ	2	2				1	3			1									13	11.4
	1																		1	0.4
σ																			0	
8	0	0			1	1					4								7	6.1
			2		1	2	1		1		1								8	3.2
DD	0	1	0		0	0			0		0								1	
							1												1	

TABLE A-4.— Concluded.

Error group	Segment																		Total	Percentage
	1048	1219	1220	1223	1228	1231	1233	1236	1242	1355	1365	1367								
Basic data totals																				
SG labels	11	7	8	(a)	5	23	15	(a)	11	9	25								114	
Other labels	18	41	42	(a)	27	12	29	(a)	21	42	21								253	
Total labels	29	48	50	(a)	32	35	44	(a)	32	51	46								367	
Digital matrix totals																				
Omission errors	2	4	1	(a)	0	1	9	(a)	0	2	19								38	33.3
Commission errors	2	0	3	(a)	0	0	0	(a)	0	5	0								10	4.0
Total errors	4	4	4	(a)	0	1	9	(a)	0	7	19								48	13.1
Labeling error characterization evaluation totals																				
Omission errors	0	3	1	0	0	0	6	0	0	1	15								26	22.8
Commission errors	1	0	3	0	0	0	1	0	0	5	0								10	4.0
Total errors	1	3	4	0	0	0	7	0	0	6	15								36	9.8

[a]Small fields procedure; no data.

TABLE A-5.– MONTANA PHASE III BLIND SITE DATA – TYPE 2 DOTS

Symbol	Segment																		Total	Percentage
	1104	1529	1531	1532	1537	1544	1730	1734	1929	1948										
K			1							3									4	10.5
α					4														4	10.5
β																				
γ_1		1						1											2	5.3
γ_2																				
ε	1	2			1		1	2											7	18.4
							1												1	5.9
λ_1																				
λ_2						2		2											4	10.5
			1	1			1		1										4	23.5
μ																				
π					1	2	5												8	21.1
				1	3		1												5	29.4

TABLE A-5.– Continued.

Symbol	Segment																		Total	Percentage
	1104	1529	1531	1532	1537	1544	1730	1734	1929	1948										
♦																				
ω																				
θ	1			1			1			6									9	23.7
ν																				
			1		2	1	1			2									7	41.2
δ																				
κ	1		2			9	3	7	5										27	
			2	1		5	2	6	2	1									19	
σ																			0	
																			0	
B	2			2	1	4	9	11	1	1									31	10.4
	6	1	1	4		5	1	4	2										24	4.8
DD	0	0	0	0			2	0											2	
						2	1												3	

TABLE A-5.– Concluded.

Error group	Segment																		Total	Percentage
	1104	1529	1531	1532	1537	1544	1730	1734	1929	1948										
Basic data totals																				
SG labels	10	3	82	14	14	45	36	50	33	10									297	
Other labels	89	54	17	36	60	54	63	49	27	49									498	
Total labels	99	57	99	50	74	99	99	99	60	59									795	
Digital matrix totals																				
Omission errors	3	3	3	1	5	12	5	17	5	9									63	21.2
Commission errors	0	0	4	3	2	7	4	7	3	3									33	6.6
Total errors	3	3	7	4	7	19	9	24	8	12									96	12.1
Labeling error characterization evaluation totals																				
Omission errors	2	3	1	1	5	3	4	10	0	9									38	12.8
Commission errors	0	0	2	2	2	4	3	1	1	2									17	3.4
Total errors	2	3	3	3	7	7	7	11	1	11									55	6.9

TABLE A-6.— MONTANA PHASE III BLIND SITE DATA — TYPE 1 DOTS

Symbol	Segment																		Total	Percentage
	1104	1529	1531	1532	1537	1544	1730	1734	1929	1948										
κ		2			(a)					2									4	18.1
α					(a)															
β					(a)															
γ_1		3			(a)			1											4	18.1
γ_2					(a)															
ε	1	1			(a)			2											4	18.1
				1			1												2	18.2
λ_1					(a)															
λ_2	1				(a)														1	4.6
μ					(a)															
π	1				(a)	1		2											4	18.1
				1				2		1									4	36.4

[a]Small fields procedure; no data.

TABLE A-6.— Continued.

Symbol	Segment										Total	Percentage
	1104	1529	1531	1532	1537	1544	1730	1734	1929	1948		
¢			2		(a)				1		3	27.3
ω					(a)							
θ	1		1		(a)			1		2	5	22.7
υ					(a)	1				1	2	18.2
δ					(a)							
κ	1		1		(a)	1 1	1 2	3 2		2 2	9	41.0
σ			1		(a)						7	63.6
B	3 4	1	2 4	2 2	(a)	1 2	1	6 8	1 2		1 16	4.6 15.0
DD	0	0	0	0	0	0	0	0	1		23 1	6.7 4.6

[a]Small fields procedure; no data.

TABLE A-6.— Concluded.

Error group	Segment																		Total	Percentage
	1104	1529	1531	1532	1537	1544	1720	1734	1929	1948										
Basic data totals																				
SG labels	8	7	6	11	(a)	19	12	20	17	7									107	
Other labels	102	47	39	31	(a)	16	25	30	15	39									344	
Total labels	110	54	45	42	(a)	35	37	50	32	46									451	
Digital matrix totals																				
Omission errors	5	6	3	0	(a)	2	1	9	0	5									31	29.0
Commission errors	0	0	2	2	(a)	2	3	4	1	5									19	5.5
Total errors	5	6	5	2	(a)	4	4	13	1	10									50	11.1
Labeling error characterization evaluation totals																				
Omission errors	4	6	1	0	(a)	1	0	6	0	4									22	20.6
Commission errors	0	0	2	2	(a)	1	1	2	1	2									11	3.2
Total errors	4	6	3	2	(a)	2	1	8	1	6									33	7.3

[a]Small fields procedure; no data.

TABLE A-7.— MINNESOTA PHASE III BLIND SITE DATA — TYPE 2 DOTS

Symbol	Segment																		Total	Percentage
	1522	1523	1513	1512	1520	1521														
X					2														2	22.2
α																				
β																				
γ_1			4			1	4												5	15.6
γ_2			2			1													3	9.4
ε	1																		1	3.1
λ_1																				
λ_2	1	2	7	1														8	9	28.1
μ																			2	22.2
π	1	1	3	3	3	5													13	40.6
		1																	4	44.4

TABLE A-7.— Continued.

Symbol	Segment																		Total	Percentage
	1522	1523	1513	1512	1520	1521														
♦																				
■																				
●																				
▼																				
		1																	1	11.1
▲						1													1	3.1
✕	1	4	1	3	2	5													16	11.0
		2		1	3	2													8	3.9
○	0		0																	
■	2	6	3	6	7	5													29	20.0
	1	7	1	2	12	4													27	13.1
▣	0	0	0	0																
					1														1	

TABLE A-7.— Concluded.

Error group	Segment																		Total	Percentage
	1522	1523	1513	1512	1520	1521														
Basic data totals																				
SG labels	9	24	47	23	11	31													145	
Other labels	51	31	11	35	49	29													206	
Total labels	60	55	58	58	60	60													351	
Digital matrix totals																				
Omission errors	4	5	17	7	2	13													48	33.1
Commission errors	0	6	0	1	7	2													16	7.8
Total errors	4	11	17	8	9	15													64	18.2
Labeling error characterization evaluation totals																				
Omission errors	3	1	16	4	0	8													32	22.1
Commission errors	0	4	0	0	5	0													9	4.4
Total errors	3	5	16	4	5	8													41	11.0

TABLE A-8.– MINNESOTA PHASE III BLIND SITE DATA – TYPE 1 DOTS

Symbol	Segment																		Total	Percentage
	1522	1523	1513	1512	1520	1521														
X																				
α																				
	1																		1	50.0
β																				
γ_1			3	1		1													5	26.3
γ_2			3		1														4	21.1
c																				
λ_1																				
λ_2			4																4	21.1
u				2		1													3	15.8
ε	2																		2	10.5

TABLE A-8.— Continued.

Symbol	Segment																		Total	Percentage
	1522	1523	1513	1512	1520	1521														
♦																				
■																				
●				1															1	5.3
▼																				
				1															1	33.0
▲																				
✕			0	1		1													2	2.4
	1																		1	0.7
○	0	1	0																1	
■	2	0		3	1	1													7	8.3
			2	1	7	1													11	7.2
▲▲	0	0	0	0																

TABLE A-8.— Concluded.

Error group	Segment																		Total	Percentage
	1522	1523	1513	1512	1520	1521														
Basic data totals																				
SG labels	3	12	28	15	8	18													84	
Other labels	45	19	14	31	23	20													152	
Total labels	48	31	42	46	31	38													236	
Digital matrix totals																				
Omission errors	2	1	10	5	1	3													22	26.2
Commission errors	2	0	0	1	0	0													3	2.0
Total errors	4	1	10	6	1	3													25	10.6
Labeling error characterization evaluation totals																				
Omission errors	2	0	10	4	1	2													19	22.6
Commission errors	1	0	0	1	0	0													2	1.3
Total errors	3	1	10	5	1	2													21	8.9

TABLE A-9.– COLORADO PHASE III BLIND SITE DATA – TYPE 2 DOTS

Symbol	Segment																		Total	Percentage
	1005	1008	1011	1091	1099	1507														
X		1																	1	4.2
α																				
β			1																1	4.2
γ_1	2	4			1														7	29.2
γ_2																				
ε			2			1													3	12.5
λ_1					1														1	4.2
λ_2			1	1															2	8.3
μ																				
π	5				1														6	25.0
				3															3	100.0

TABLE A-9.-- Continued.

Symbol	Segment																		Total	Percentage
	1005	1008	1011	1091	1099	1507														
♦																				
∞																				
θ																				
ν																				
δ	3																		3	12.5
κ	1	1	3		0	1													6	5.3
	1		12	2															15	5.2
σ																				
B	5	1	2	2	2	2													14	12.3
	8	2	2	3	0	0													15	5.2
DD	0	0	0	0	0	0														

TABLE A-9.– Concluded.

Error group	Segment																		Total	Percentage
	1005	1008	1011	1091	1099	1507														
Basic data totals																				
SG labels	22	9	12	56	11	4													114	
Other labels	38	51	88	4	49	56													286	
Total labels	60	60	100	60	60	60													400	
Digital matrix totals																				
Omission errors	11	6	7	1	3	2													30	26.3
Commission errors	1	0	12	5	0	0													18	6.3
Total errors	12	6	19	6	3	2													48	12.0
Labeling error characterization evaluation totals																				
Omission errors	10	5	4	1	3	1													24	21.1
Commission errors	0	0	0	3	0	0													3	1.1
Total errors	10	5	4	4	3	1													27	6.8

TABLE A-10.— COLORADO PHASE III BLIND SITE DATA — TYPE 1 DOTS

Symbol	Segment																		Total	Percentage
	1005	1008	1011	1091	1099	1507														
X			(a)																	
α			(a)																	
β			(a)																	
γ_1			(a)																	
γ_2	1		(a)			1													2	25.0
ε			(a)			1													1	12.5
λ_1			(a)																	
λ_2			(a)		2														2	25.0
μ		1	(a)																1	12.5
π			(a)			1														
		1																	1	12.5
																			1	100.0

[a]Small fields procedure; no data.

TABLE A-10.— Continued.

Symbol	Segment																		Total	Percentage
	1005	1008	1011	1091	1099	1507														
ϕ	1		(a)																1	12.5
ω			(a)																	
θ			(a)																	
ν			(a)																	
ξ			(a)																	
κ	1	1	(a)	2	0	2													6	17.6
σ			(a)																	
β	3	2	(a)		0	2													7	20.6
	3			1		2													6	3.6
DD	0	0	(a)	0	0	0														

[a]Small fields procedure; no data.

TABLE A-10.— Concluded.

Error group	Segment																		Total	Percentage
	1005	1008	1011	1091	1099	1507														
Basic data totals																				
SG labels	7	5	(a)	4	11	7													34	
Other labels	29	36	(a)	39	23	39													166	
Total labels	36	41	(a)	43	34	46													200	
Digital matrix totals																				
Omission errors	3	2	(a)	2	2	5													14	41.2
Commission errors	0	1	(a)	0	0	0													1	0.6
Total errors	3	3	(a)	2	2	5													15	7.5
Labeling error characterization evaluation totals																				
Omission errors	2	1	(a)	0	2	3													8	23.5
Commission errors	0	1	(a)	0	0	0													1	0.6
Total errors	2	2	(a)	0	2	3													9	4.5

[a]Small fields procedure; no data.